Bose-Einstein condensation; Quantum weirdness at the lowest temperature in the universe

JILA BEC Effort Eric Cornell, Carl Wieman **1990-**

Anderson, Ensher, Jin, Hall, Matthews, Myatt, Monroe, Claussen, Roberts, Cornish, Haljan, Donley, Thompson, Papp, Zirbel, Lewandowski, Harber, Coddington, Engels, McGuirk, Hodby,...

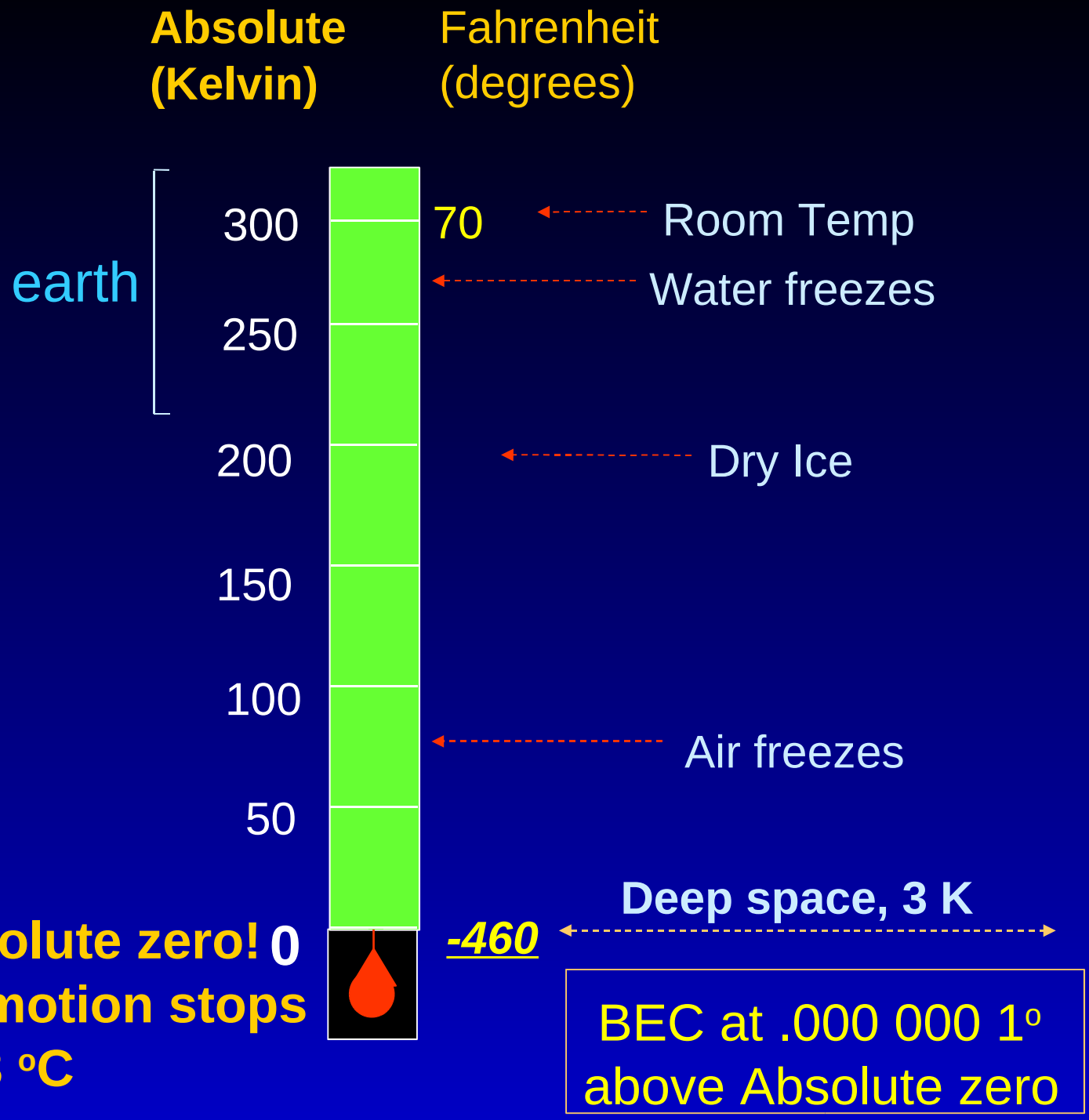
$$ (NSF, ONR, NIST)

Part I. (1924-95) Making Bose-Einstein Condensation in a gas.

BEC- a new form of matter predicted by Einstein in 1924 and first created in 1995 by our group.

Part II. An example of recent research with BEC.

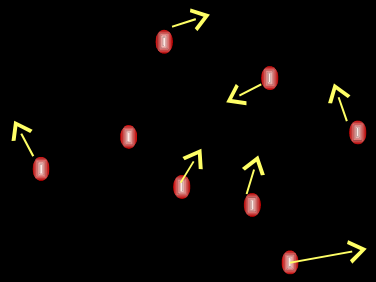
temperature applet

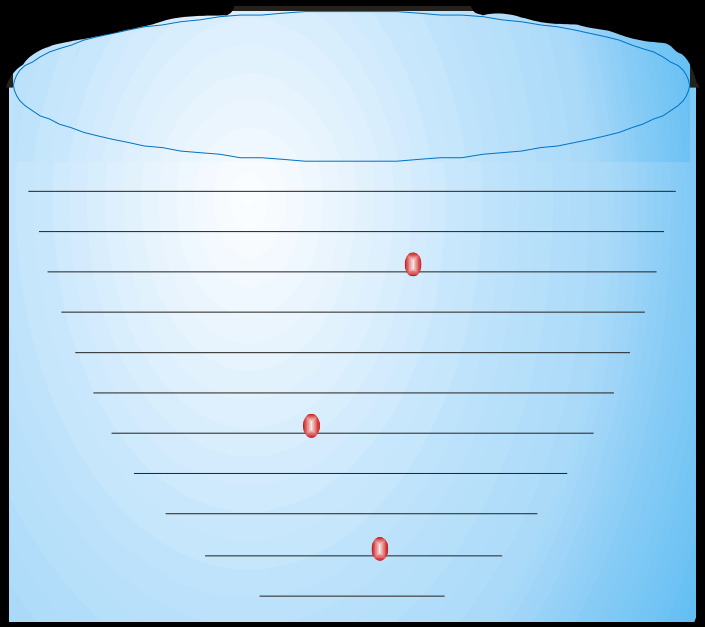

Absolute (Kelvin)
Fahrenheit (degrees)
earth
300
250
200
150
100
50
0
70
-460
Room Temp
Water freezes
Dry Ice
Air freezes
Deep space, 3 K
Absolute zero!
All motion stops
-273 °C
BEC at .000 000 1° above Absolute zero


CSIU

Hot atoms

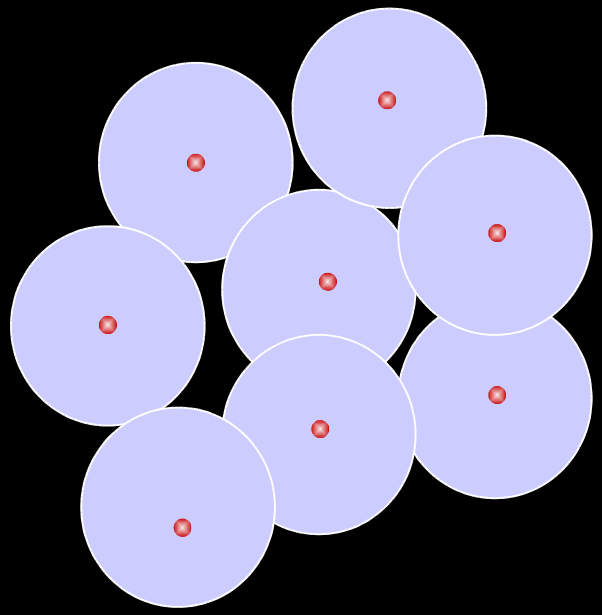
(more than 10 millionths of degree above abs. zero)



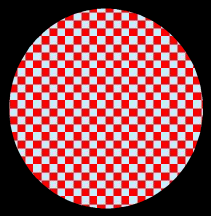


Cold atoms

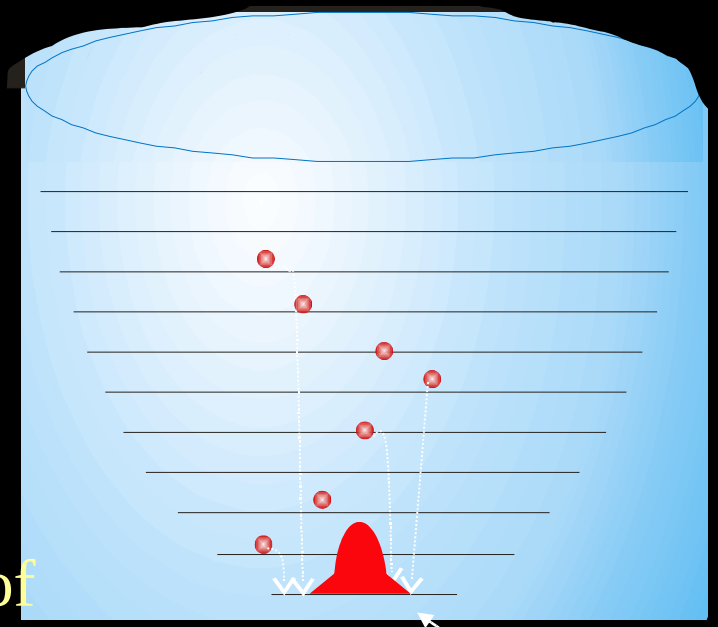
A. E. 1924



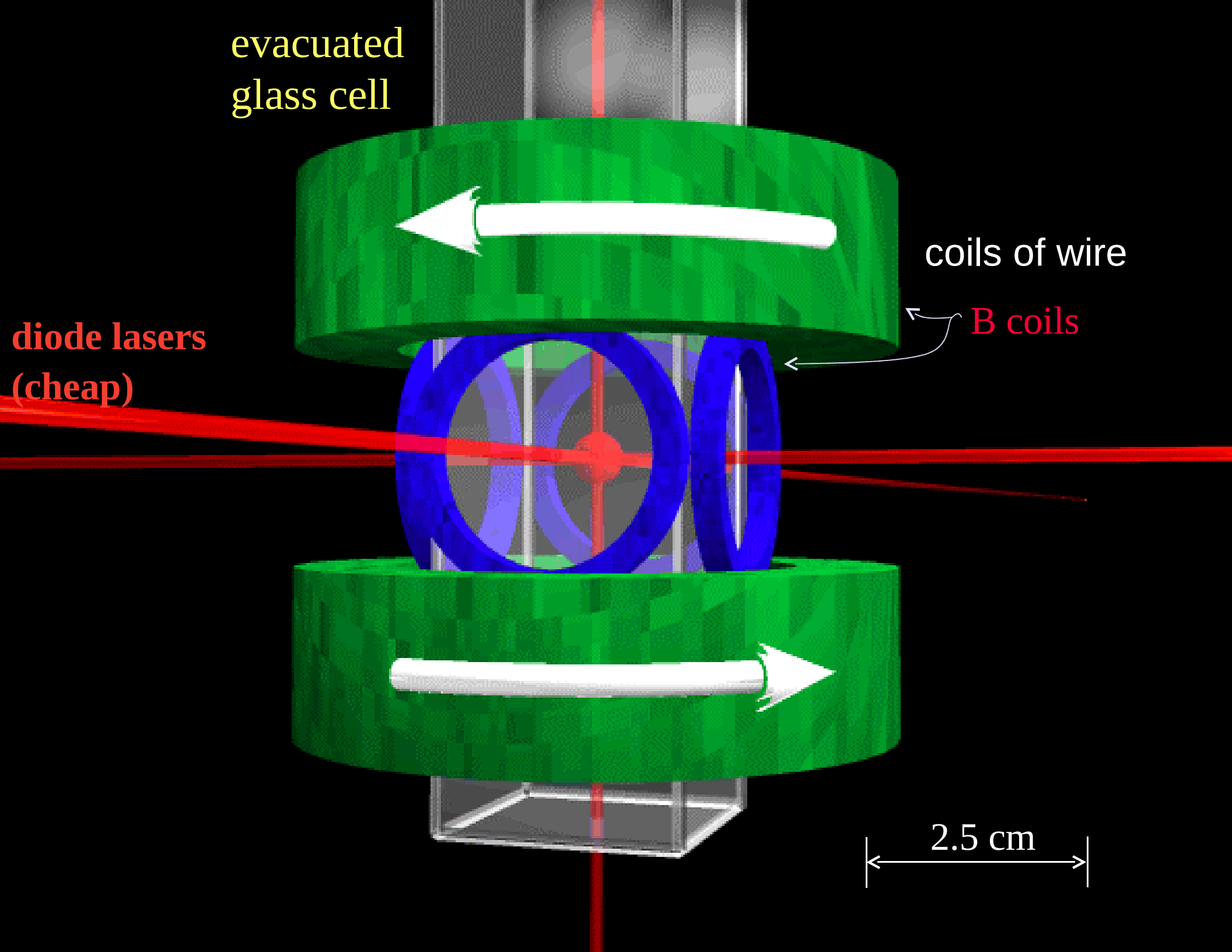
BEC



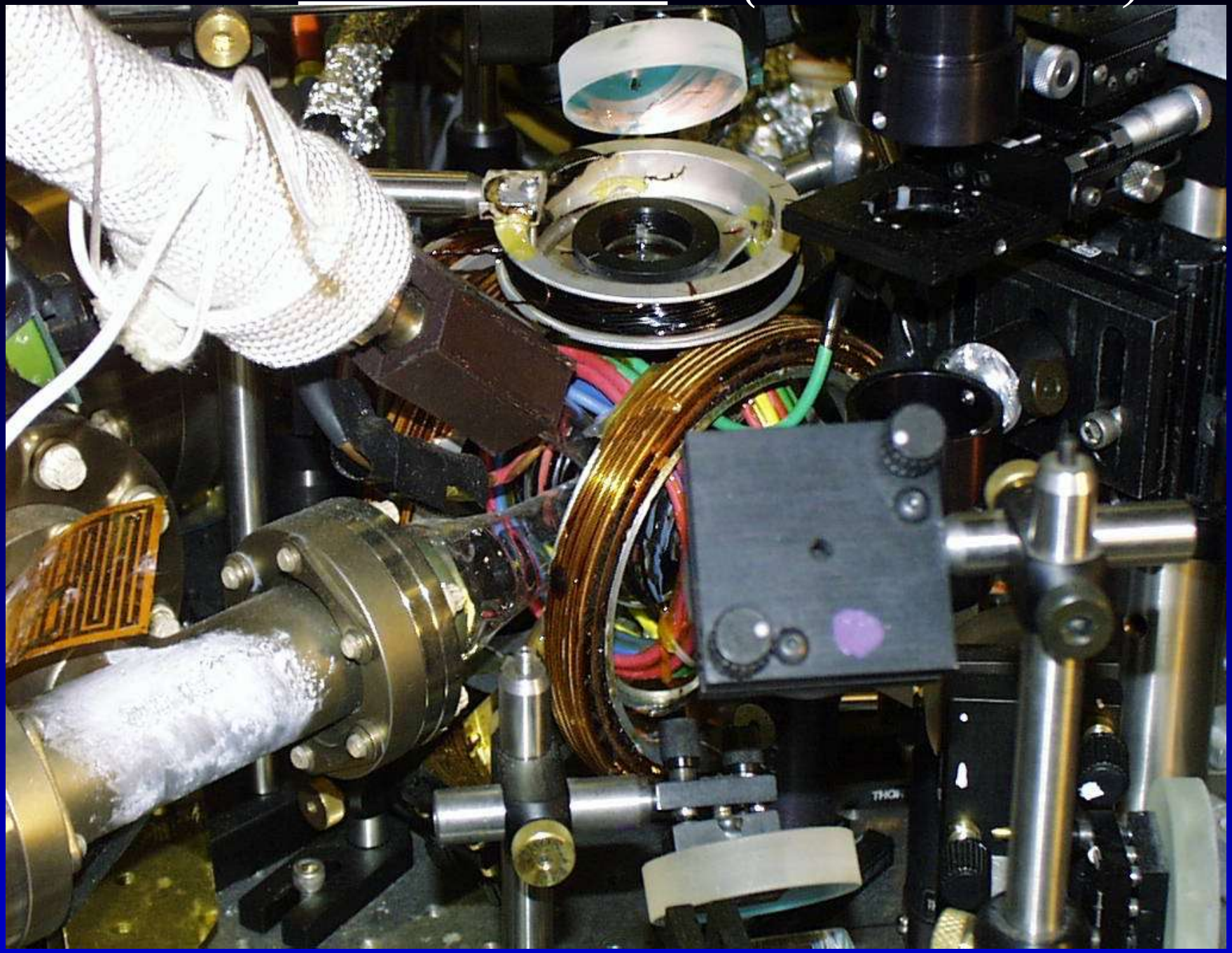
100 billionths of a degree



"superatom" --single quantum wave

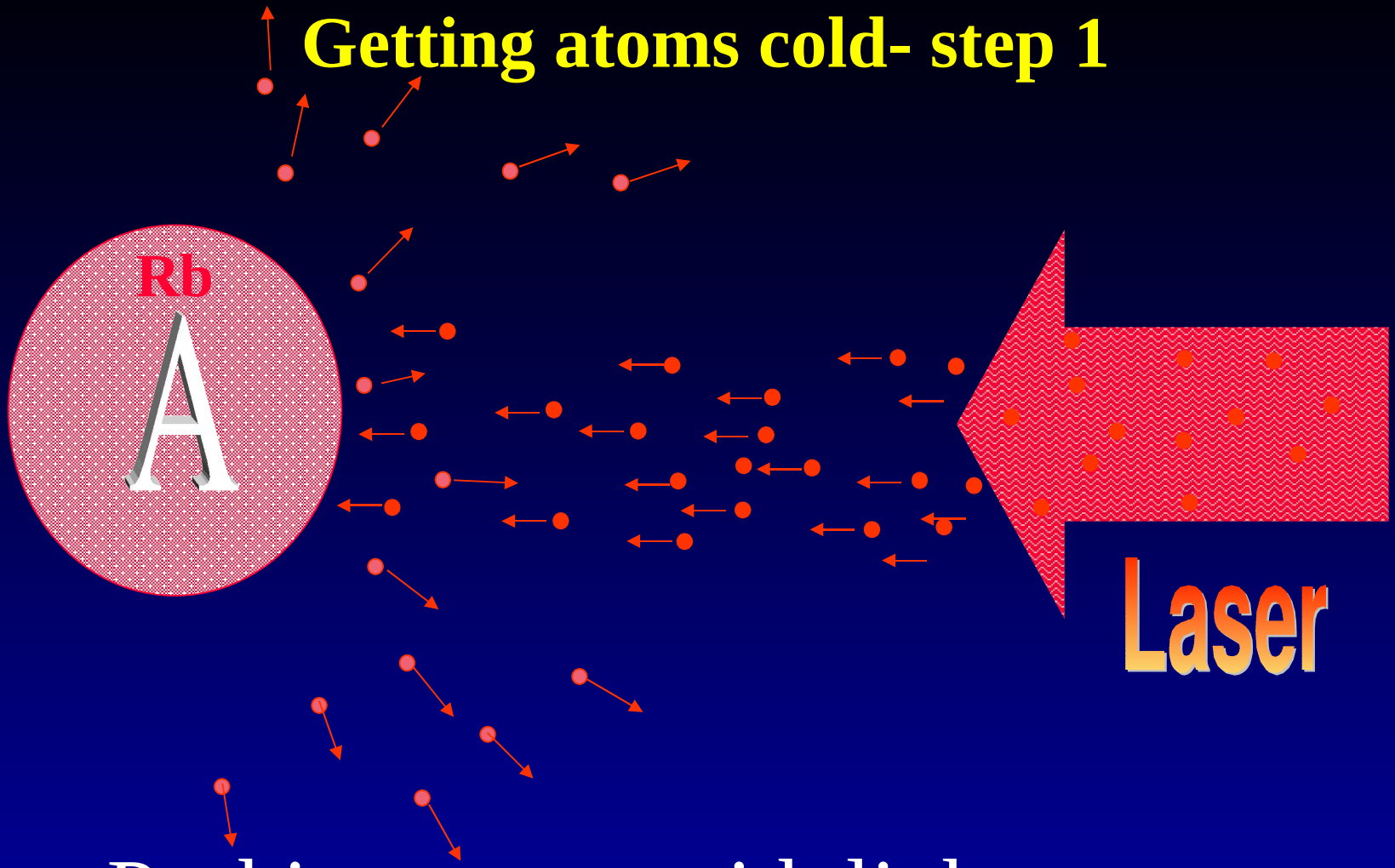

evacuated
glass cell
coils of wire
B coils
diode lasers
(cheap)
2.5 cm

JILA BEC #2 *(#1 at Smithsonian)*



Grad students Neil Claussen, Sarah Thompson, postdoc Liz Donley working on BEC experiment.

Getting atoms cold- step 1

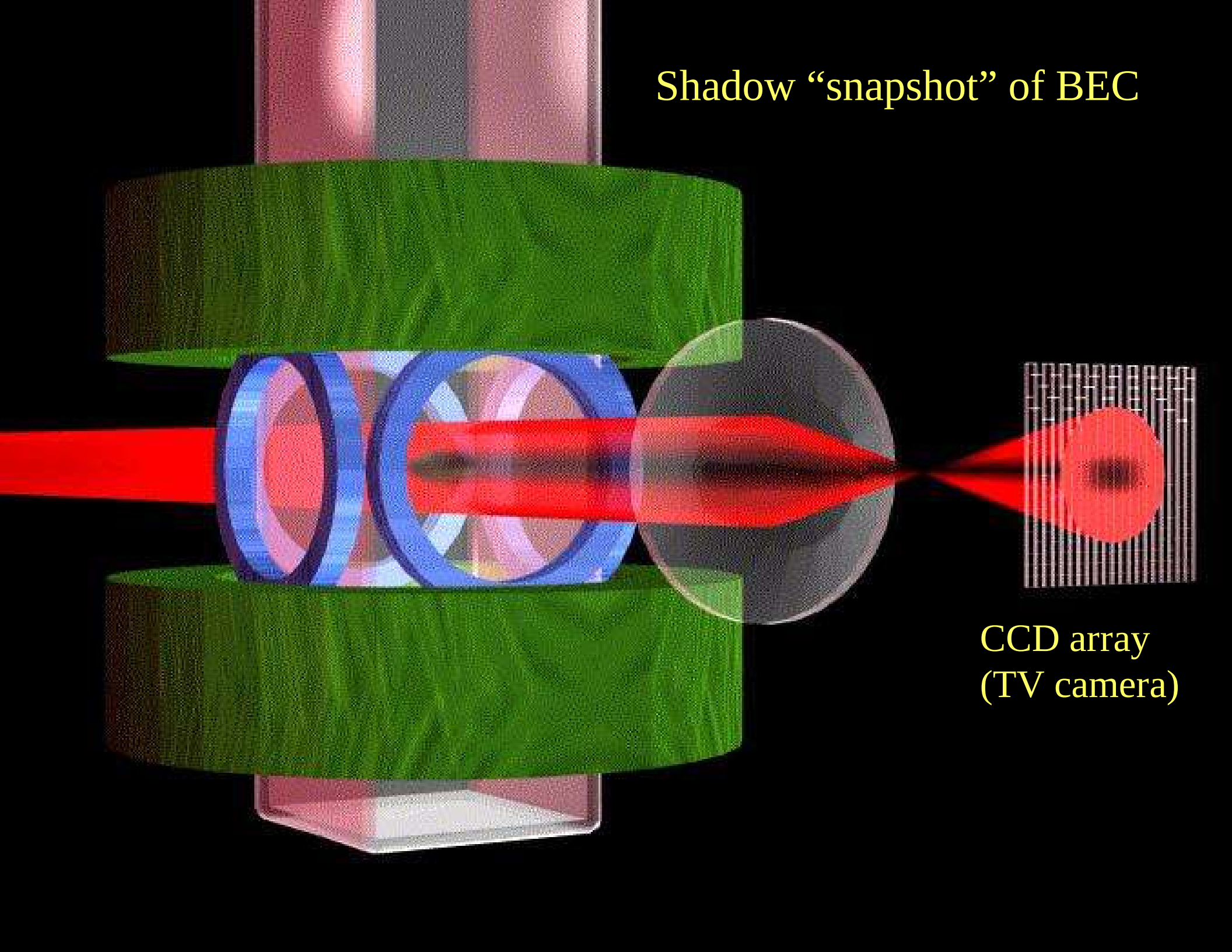


Pushing atoms with light

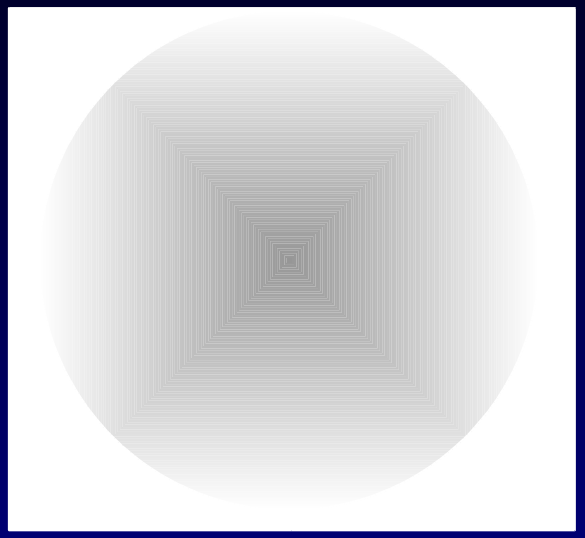
Why does sunlight heat you up, but laser light cools these atoms down?

laser cooling applet

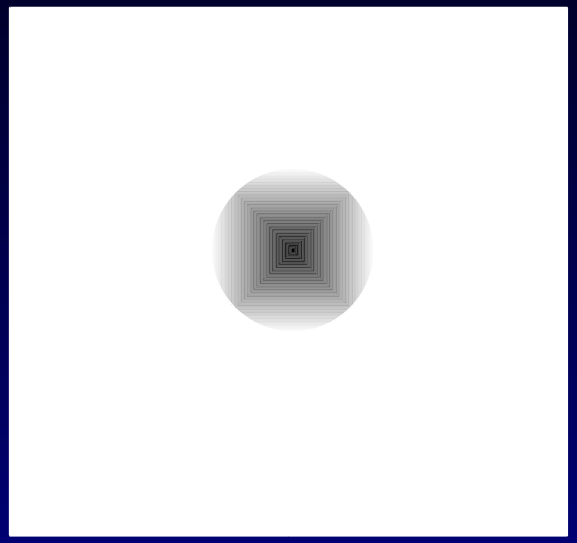
optical molasses applet
magnetic trapping applet
evaporative cooling applet


Shadow “snapshot” of BEC
CCD array
(TV camera)

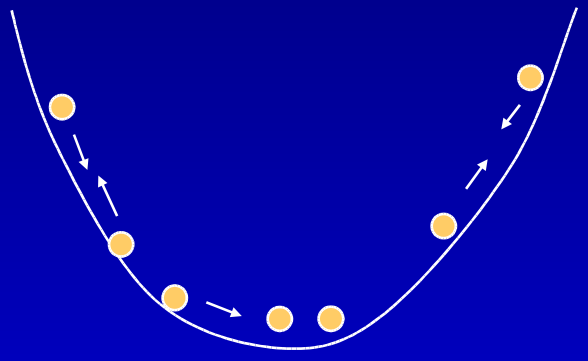
Shadow images of clouds

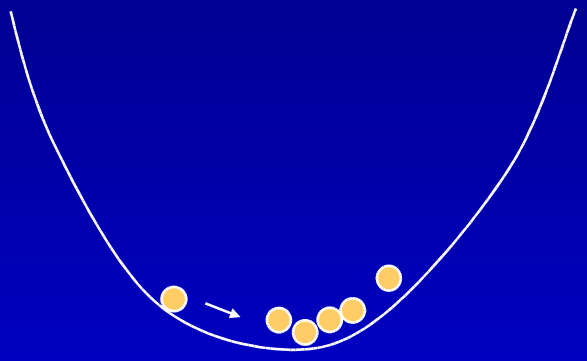


Hot cloud



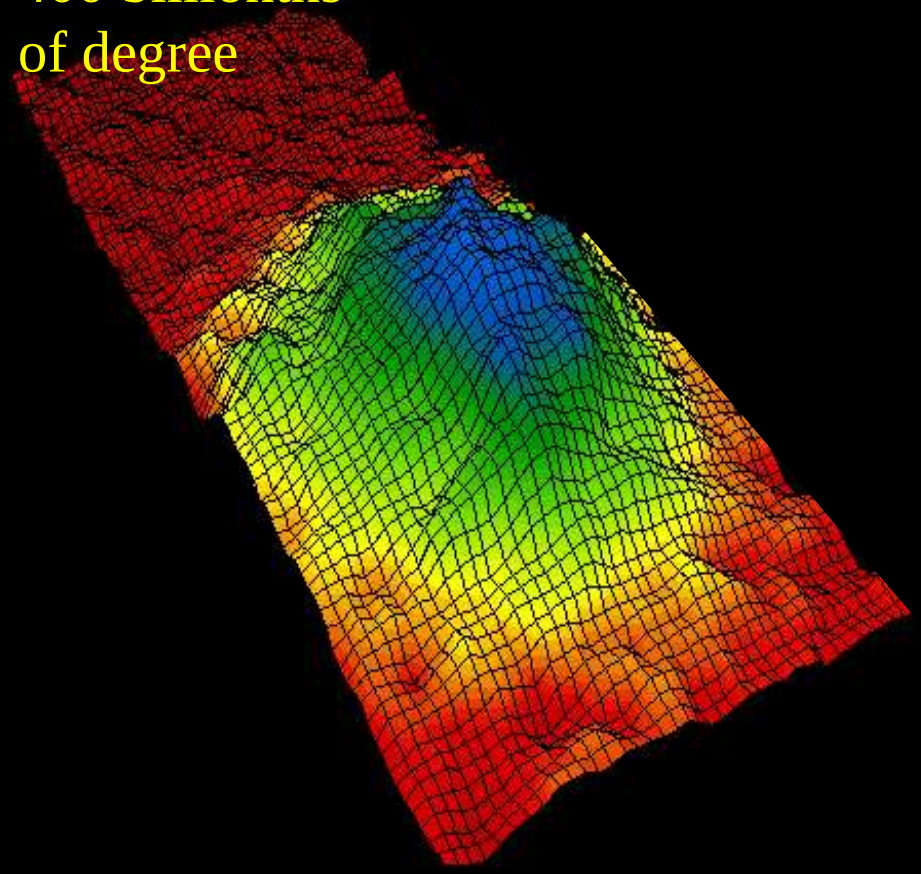
Cold cloud

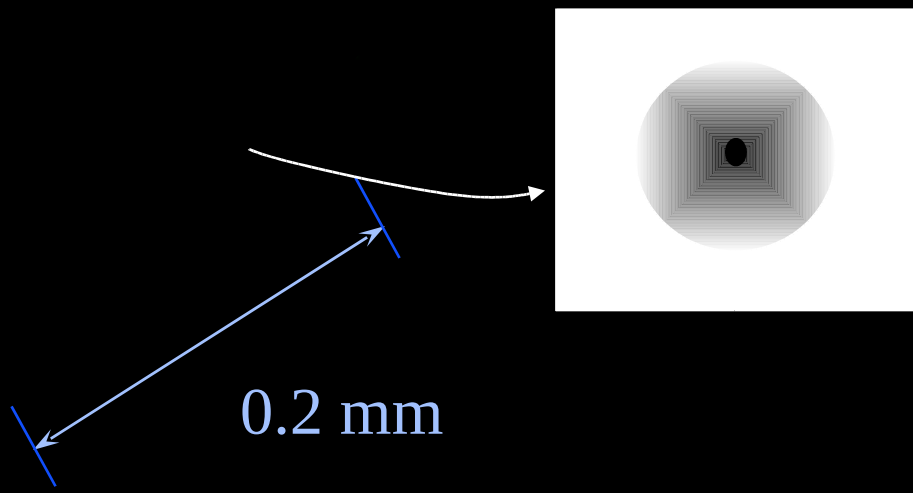




BEC! JILA 1995

400 billionths
of degree

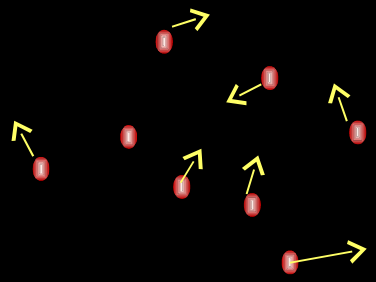


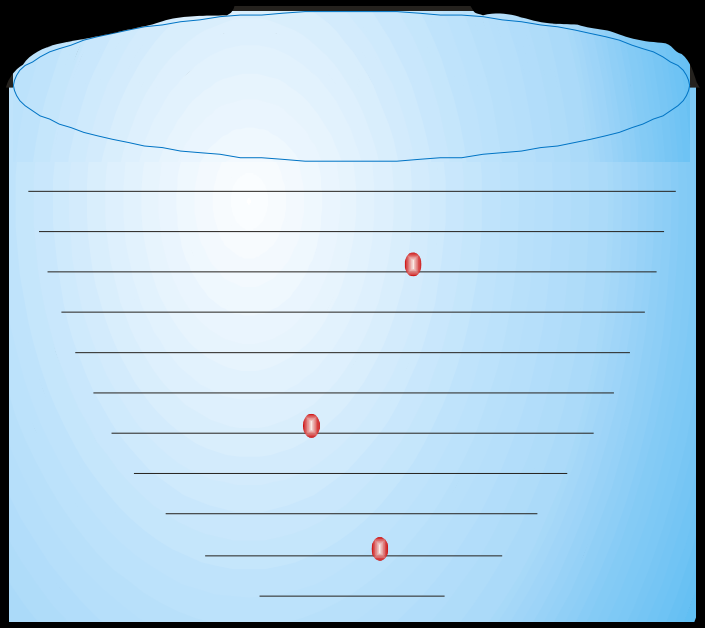


False color images of cloud

Hot atoms

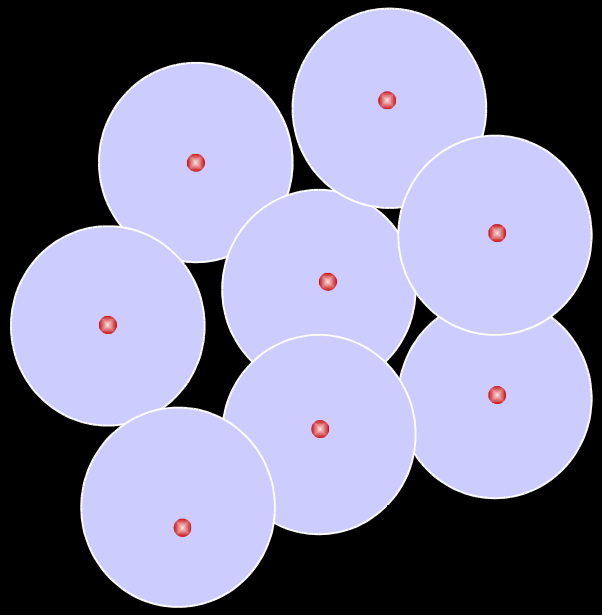
(microKelvins)



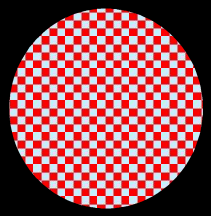


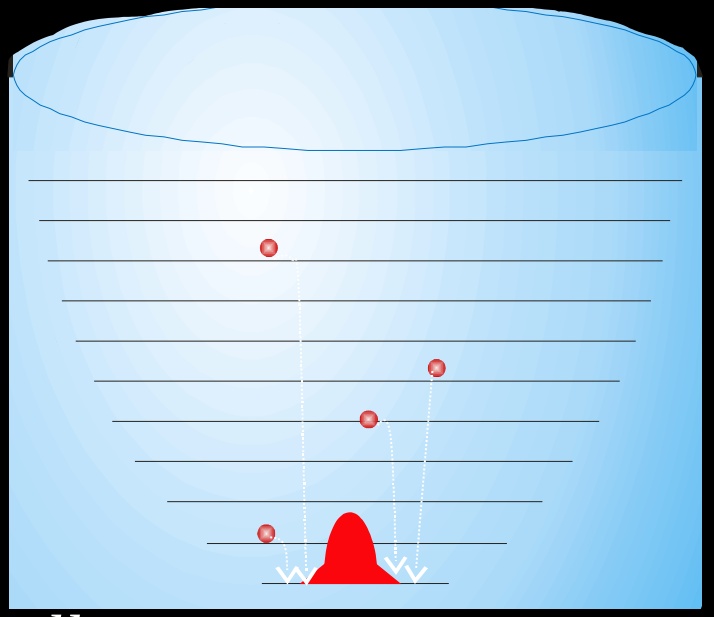
Cold atoms

A. E. 1924



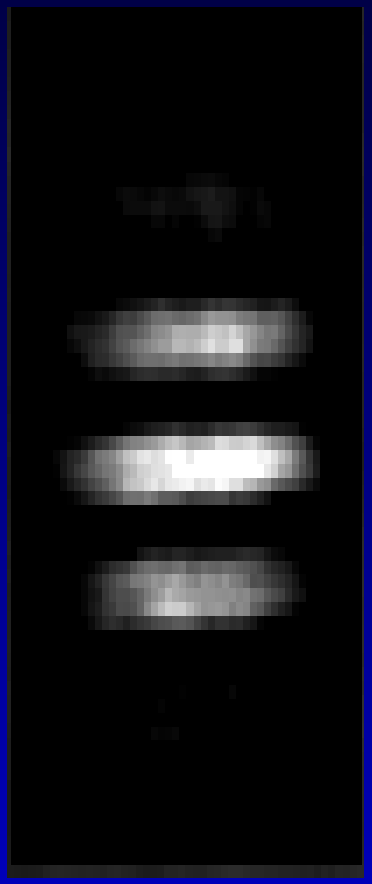
Bosons





lowest level smallest width- set by uncertainty principle

Quantum physics on “human” size scale
Control and Observe



Putting one condensate on top of another

about width of human hair

Fringes formed with two overlapping condensates- waves interfering.

(NIST Gaithersburg atom cooling group - courtesy S. Rolston)

Where BEC now (post June '95)?

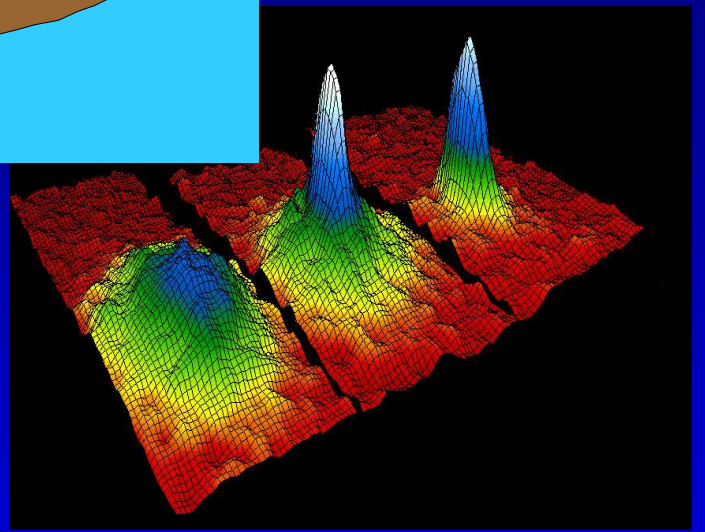
New regime of physics-
directly observe and manipulate quantum wave function

~ 200+ working experiments, many atoms (^{87}Rb, Na, Li, H, ^{85}Rb, He*,K, Cs

} *>1000 scientists*

countless theorists-

many thousands of papers



- Measured and predicted all sorts of novel properties.
- New ways to study, make and manipulate.
- Potential applications.

Stockholm Sweden, Dec. 10, 2001

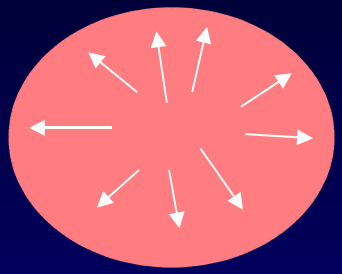
Part II. Some recent research.

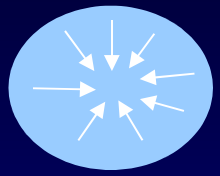
New material. Explore behavior, find occasional surprises, understand $\Rightarrow$ new knowledge about laws of nature.

$\Rightarrow$ science advances.

Controlling self-interactions with ^{85}Rubidium BEC

Roberts, Claussen, Donley, Thompson, CEW





repulsive (^{87}RB, Na), $a > 0$

attractive (Li, ^{85}Rb), $a < 0$

(unstable if N large, $N_{max} \propto 1/a$)

in 85 Rb have experimental knob to adjust from large repulsive to nothing to large attractive!

3 billionths of a degree!

Magnetic field

(like knob to control gravity)

Plunging into the unknown– interaction attractive

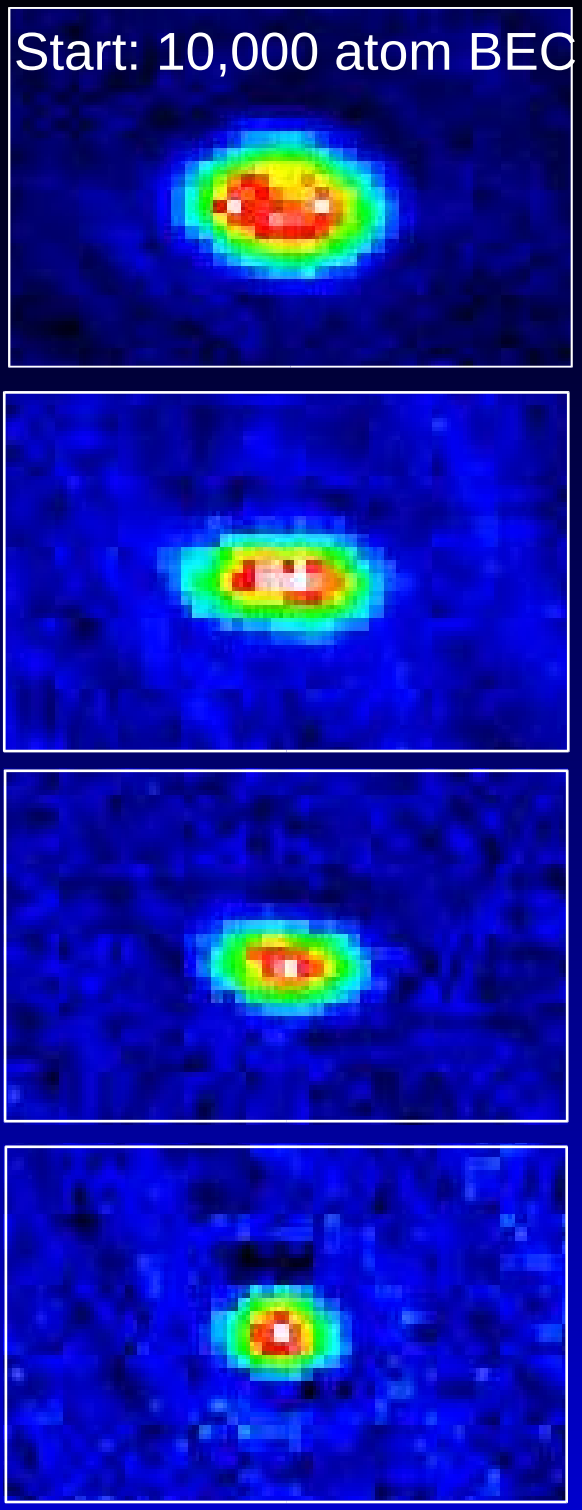
Lots of theory, varied wildly.
Little data

1. Make BEC magnetic field where repulsive

2. Switch to attractive.

What happens?

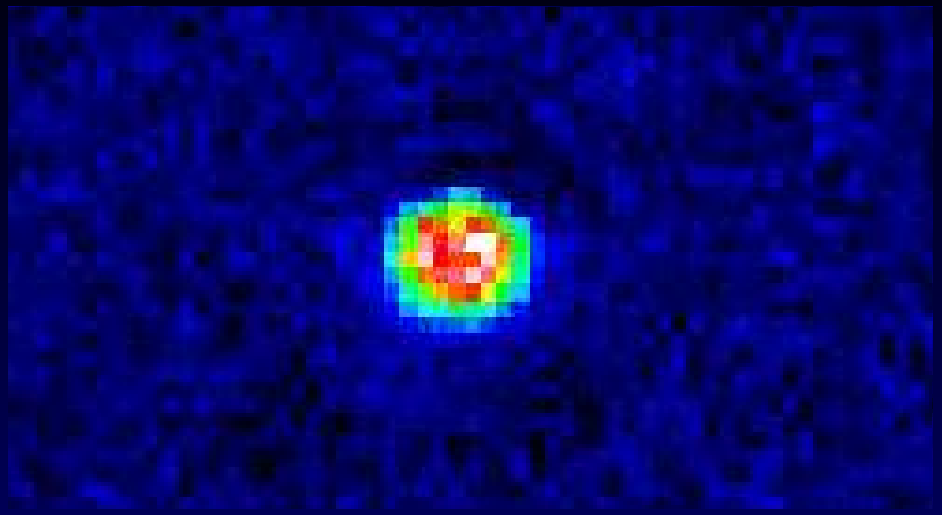
(how do quantum wavefunctions die?



Collapse

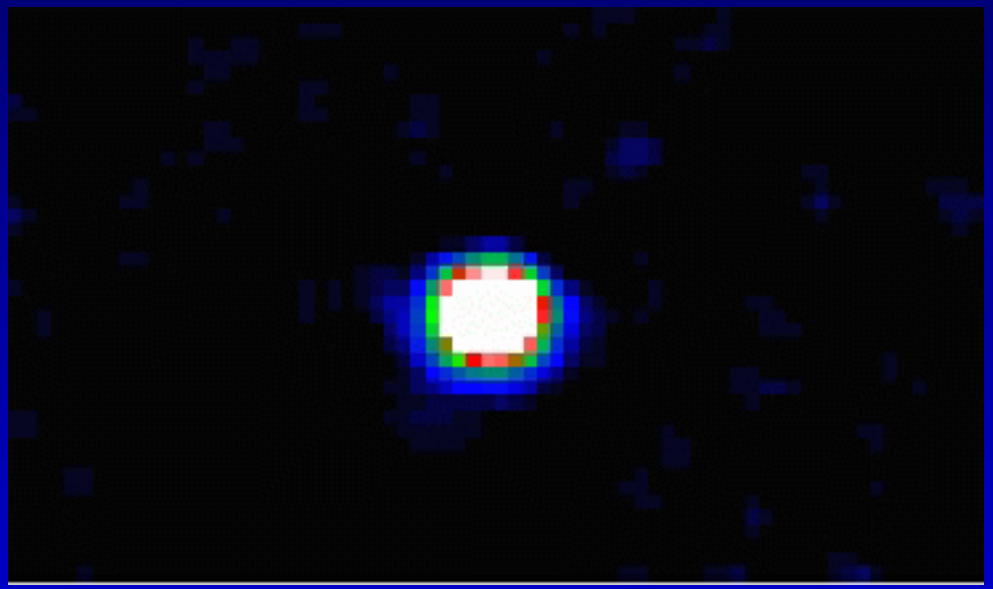
time

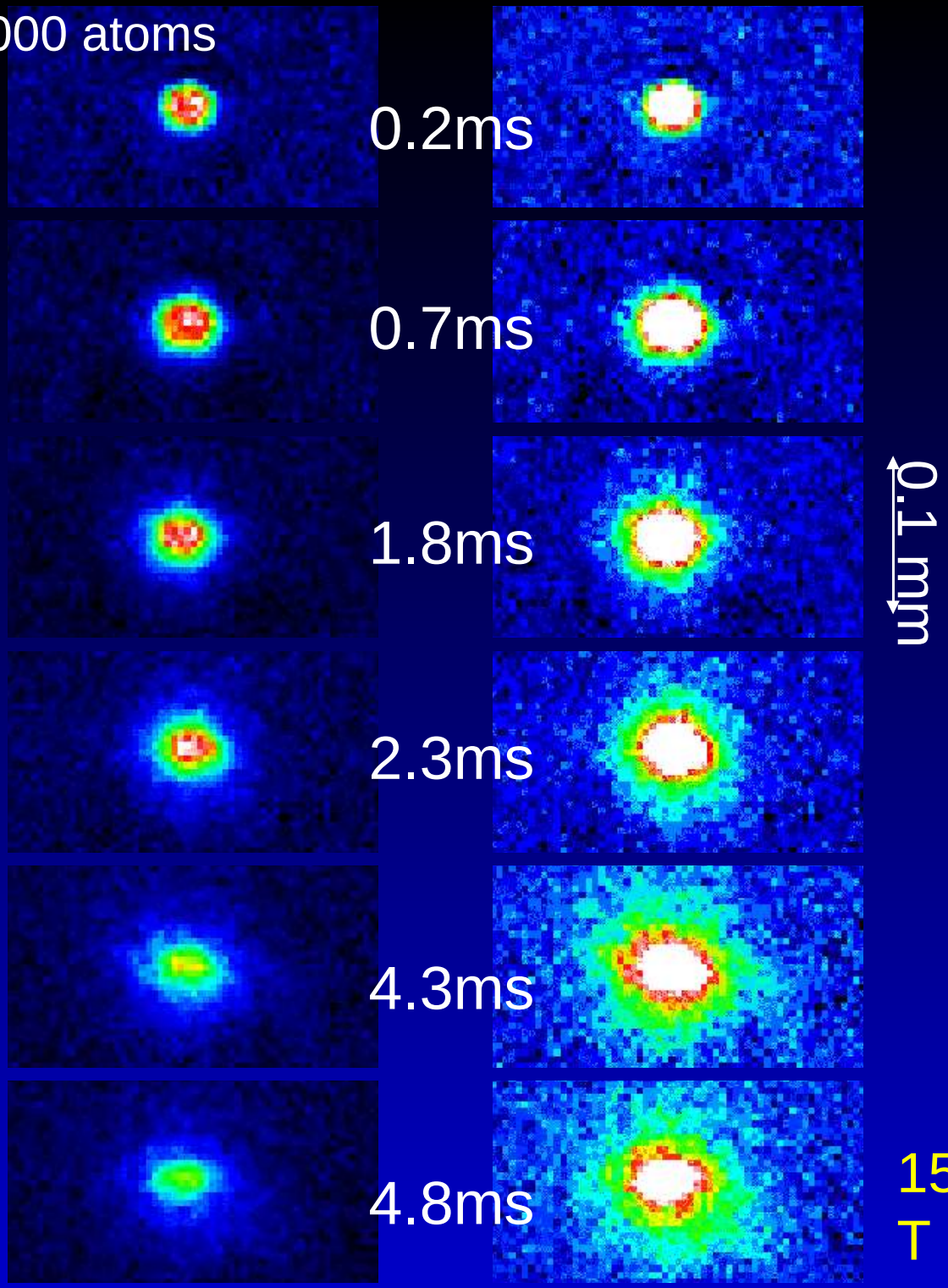
then…



x 3

Explosion !!





like supernova:

- collapse
- explosion… (x 10^{-73})
- cold remnant

"Bosenova"

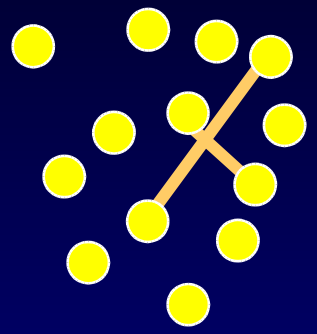
What is the physics of explosion???
Why remnant remains?

progress…

1500 atom explosion
T ~ 200 nK

source of energy of Bosenova--chemical

A New Type of Chemistry--

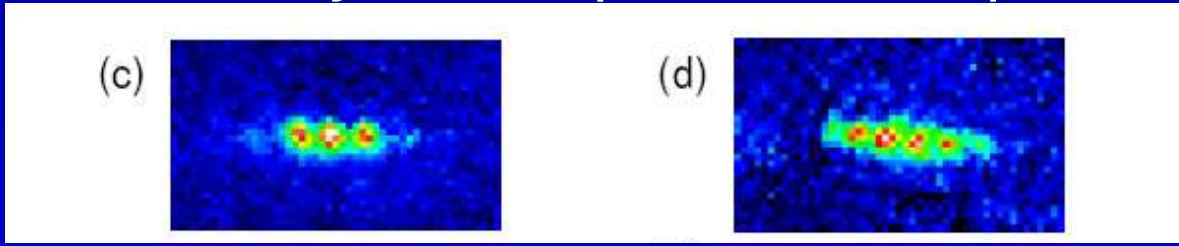


changing magnetic field just right turns atoms in BEC into unusual Rb_2 "molecules".

- 10,000 times larger than normal molecules
- new formation processes
- busy studying

Why remnant remains?

2006
BEC finds way to collapse into multiple BEC “solitons”--robust



What is next ?

(what is it good for?)

I. Measure and understand properties.

New area of quantum world to explore–
turning BEC atoms into strange new sort of molecules

II. Uses (??).... 5-20 years *("laser-like atoms")*

a. Ultrasensitive detectors (time, gravity, rotation).
making a quantum computer(?).

b. Making tiny stuff--putting atoms ***exactly*** where want them

simulations shown (and more)
www.colorado.edu/physics/2000/ see BEC section

interactive simulations for learning lots of other physics
PHET.Colorado.edu